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SUBJECT: CSM RCS Requirements for Inertial
Holds of the Orbital Assembly
Case 600-3

DATE: February 17, 1967

FROM: W. W. Hough

ABSTRACT

Two configurations of the Orbital Assembly for AAP
missions 3 and 4 are presently under consideration. The first,
with the LM-ATM docked to a side port of the multiple docking
adapter and the CSM docked to the forward port, requires
minimum RCS propellant for control moment gyro momentum unload-
ing and provides the most advantageous thermal environment for
the Workshop. The second configuration, with the position of
the LM-ATM and CSM interchanged, allows the same Airlock Module
solar panel orientation for the ATM mission and for a gravity-
gradient stabilized Workshop in missions 1 and 2, and is
advantageous from a passive attitude control standpoint if the
LM-ATM is to dock before the CSM. This memorandum presents an
analysis of one of the factors, the CSM RCS requirement for CMG
momentum unloading, for the two configurations, LM on the side
and LM on the end.

If opposed CSM RCS jets are fired as a couple, the
RCS requirements for 56 days of CMG stabilization are 320 pounds
for LM on the side and 3148 pounds for LM on the end. In the
latter case, a greater net torque can be obtained with the same
RCS thrust by firing CSM translational jets. This is due to a
relatively large moment arm between the thrusters and the
assembly center of mass. This method reduces the RCS requirements
for LM on the end to 1292 pounds. The same scheme is not
appropriate for the LM on the side case because the steady
component of gravity-gradient torque acts about the CSM roll
axis, and coupled roll jets must be used to apply a counter
torque.

The minimum factor-of-four increase in RCS requirements
for LM on the end and resulting increased crew involvement and
combustion products lead to the recommendation that the LM on
the side configuration be implemented. Airlock Module solar
panels must be made compatible with this orientation. Either
manual articulation of the panels or an attitude suitable for
side-looking panels must be implemented for the first Workshop
mission.

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MEMORANDUM FOR FILE

An inertial attitude of the Orbital Assembly
(AAP-3/AAP-4) where its axis of minimum moment of inertia
is kept in the orbital plane minimizes the RCS fuel require-
ment for unloading accumulated angular momentum from the
control moment gyros. To maintain this attitude and also
point a (relatively) fixed ATM at the sun, the LM-ATM must
be docked to the side of the multiple docking adapter (MDA).
A detailed description of this attitude and the Orbital
Assembly configuration was given in a previous report.*

Another configuration, with the LM docked to the
forward port of the MDA, is also under consideration. This
location would allow the same Airlock Module solar panel
orientation for the ATM mission and for a gravity-gradient
stabilized Workshop in the AAP-1/AAP-2 mission. However, in
the ATM mission, it would require positioning of the roll
axis of the Orbital Assembly along the sun line. The bias
or steady component of gravity-gradient torque is substantially
increased in this orientation except in the special case when
the intersection of orbital and ecliptic planes is coincident
with the sun line. This steady torque results in bias
momentum accumulation by the CMG's and accumulation to maximum
CMG capacity necessitates unloading by CSM RCS firing.

With one principal axis in the orbital plane, the
RCS requirement per orbit when firing two jets as a couple
with a 12.8 foot separation is:

$$W_{RCS} = 2.92 \times 10^{-6} (I_A - I_B) \sin 2\theta \text{ pounds}$$

*G. M. Anderson, W. W. Hough. "Hard-Docked ATM Experiment
Carrier", Bellcomm TM-66-1022-1, November 18, 1966.

where $(I_A - I_B)$ is the positive difference between the principal moments of inertia about the other two axes in slug ft ^{2} and θ is the angle between the orbital plane and the principal axis most closely aligned with the ATM optical axis. The inertia tensors for each Assembly configuration, LM on the side and LM on the end, have been evaluated. The reference axis system is:

x = axis parallel to Workshop centerline

y = axis parallel to M&SS and side-docked vehicle centerline

z = axis perpendicular to Workshop and side-docked vehicle centerlines.

For a total Assembly mass of 3155 slugs[*], the inertia tensor,

$$
\begin{bmatrix}
I_{xx} & - I_{xy} & - I_{xz} \\
- I_{xy} & I_{yy} & - I_{yz} \\
- I_{xz} & - I_{yz} & I_{zz}
\end{bmatrix}
$$

is:

A. LM on the Side

$$
I_{xyz} = \begin{bmatrix}
365.62 & 90.67 & 0 \\
90.67 & 2893.92 & 0 \\
0 & 0 & 3099.18
\end{bmatrix} \times 10^3 \text{ slug ft }^2
$$

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[*]The total Assembly mass is the sum of the following estimated masses:

CSM, including resupply provisions	- 940 slugs	(30250 pounds)
LM-ATM	- 544 slugs	(17500 pounds)
M&SS Payload Module	- 187 slugs	(6000 pounds)
Airlock Module, including solar panels	- 392 slugs	(12600 pounds)
S-IVB Workshop, IU, & SLA	-1016 slugs	(32700 pounds)
Multiple Docking Adapter	- 76 slugs	(2450 pounds)

B. LM on the End

$$I_{xyz} = \begin{bmatrix} 537.72 & 253.78 & 0 \\ 253.78 & 2462.99 & 0 \\ 0 & 0 & 2840.35 \end{bmatrix} \times 10^3 \text{ slug ft}^2$$

Diagonalization yields principal inertia tensors:

A. LM on the Side

$$I_p = \begin{bmatrix} 362.37 & 0 & 0 \\ 0 & 2897.17 & 0 \\ 0 & 0 & 3099.18 \end{bmatrix} \times 10^3 \text{ slug ft}^2$$

B. LM on the End

$$I_p \begin{bmatrix} 504.83 & 0 & 0 \\ 0 & 2495.88 & 0 \\ 0 & 0 & 2840.35 \end{bmatrix} \times 10^3 \text{ slug ft}^2$$
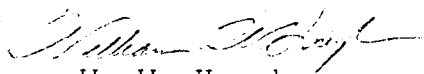
For LM on the side, the principal axis of minimum moment of inertia is positioned in the orbital plane and $(I_A - I_B)$ is 202.01 x 10^3 slug ft ^{2}. For LM on the end, either the axis of intermediate or maximum moment of inertia may be positioned in the orbital plane, with the latter resulting in the smallest requirement for RCS fuel. $(I_A - I_B)$ in this case is 1991.05 x 10^3 slug ft^2. RCS fuel requirements for the two configurations have exactly the same ratios as these inertia differences. In other words, LM on the end

requires $\frac{1991.05}{202.01}$ = 9.86 times as much fuel for CMG momentum
unloading as does LM on the side if the jets are fired as a
couple. The total RCS requirement for this task over 850
orbits (approximately 56 days), where sin 2θ varies between
0 and 1, are 320 pounds for LM on the side and 3148 pounds
for LM on the end.

The fuel requirements for the LM on the end case
can be reduced by firing CSM translational jets if a set of
these is orientated perpendicular to the principal axis that
is kept in the orbital plane. The line of action of
translational jets orientated in this fashion is 15.6 feet
from the center of mass of the Assembly. They can apply the
same torque with $\frac{6.4}{15.6}$ = .41 times as much fuel. (6.4 feet is
the equivalent moment arm of the two coupled jets.) Minimum
total fuel requirements for LM on the end are therefore
.41 x 3148 = 1292 pounds. Translational jets cannot be used
to advantage in the LM on the side case because the steady
component of gravity-gradient torque acts about the in-plane
Assembly axis which is approximately coincident with the CSM
roll axis. Only CSM roll jets, which are coupled, can be used
to apply a counter torque. However, even with the best possible
circumstances for the LM on the end configuration (axis of
maximum moment of inertia held in the orbital plane and a set
of CSM translational jets aligned perpendicular to that axis),
this case requires over four times the RCS propellant than the
LM on the side configuration.

The case of LM on the side presents RCS requirements
that, when combined with the other requirements on the AAP-3
CSM system, are in line with the enhanced 2400 pound capacity.
LM on the end, however, needs over half of the propellant
quantity for CMG unloading. CMG momentum must be unloaded
much more frequently, which increases crew involvement for
manual RCS operation. Any adverse effects on the ATM experi-
ments caused by products of RCS combustion are substantially
increased. These considerations lead to the recommendation
that the ATM mission be performed with the LM-ATM docked to
the side of the MDA. Airlock Module solar panels must be
compatible with this orientation and will therefore have to
be equipped with a manual articulation mechanism if the first
Workshop mission is flown in a gravity-gradient stabilized
attitude, or the first mission must be flown in an attitude
compatible with fixed side-looking panels.

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